Breakthrough Data Link Technologies for Enhanced Weather Dissemination

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Outline

Honeywell

- **Need for aeronautical datalinks**
- **Single chip transceiver for aeronautical datalinks**
- **Reconfigurable, electronically steered antenna**

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The Need for Aerospace Datalinks

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- Aerospace datalink needs are unique and cannot be satisfied by the commercial telecom industry.
- Key elements of terrestrial communication technology can be applied to aeronautical communications.
- Examples:
  - ASIC technology for VHF datalinks
  - Reconfigurable antenna technology to optimally access telecom infrastructure

Outline

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- ***Single chip transceiver for aeronautical datalinks***
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Radio on a Chip Technology (ROC)

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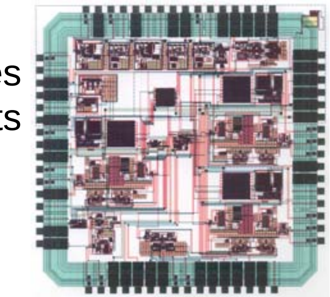
ASIC RF system implementation enables the functionality, cost, and size of many familiar products

Commercial ROC addresses several high volume markets (SSEC)



Mainstream IC market does not address avionics communications market effectively

- Relatively low volumes
- Product obsolescence requires lifetime buys

Implementing RF and Wireless solutions in chip form has many advantages

Single Chip Transceiver Program Goals

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- Develop a single chip transceiver capable of operating from at least marker beacon frequencies (75MHz) to the top of the MilCom band (450MHz)
- Input third order intercept of at least +4dBm (for VDL mode-2)
- Integrate VCOs and synthesizers on-chip
- Fabricate in commercial CMOS technology
- Operate from 3-5V supplies
- Develop for low power consumption for potential battery operation

Single Chip Transceiver Design Features

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- High, third-order intercept, low-noise amplifier/mixer
- Linear intermediate frequency automatic gain control response
- Integral vector (I/Q) baseband demodulator
- Integral vector (I/Q) baseband modulator
- Power controlled transmitter
  - 10mW max output power
- Integral synthesizers
  - Fractional-N design for 1st LO, Integer-N for 2nd & 3rd LO's
  - External tank circuits and tuning varactors for maximum flexibility

Designed for maximum flexibility to allow for a broad range of applications

Receiver Architecture

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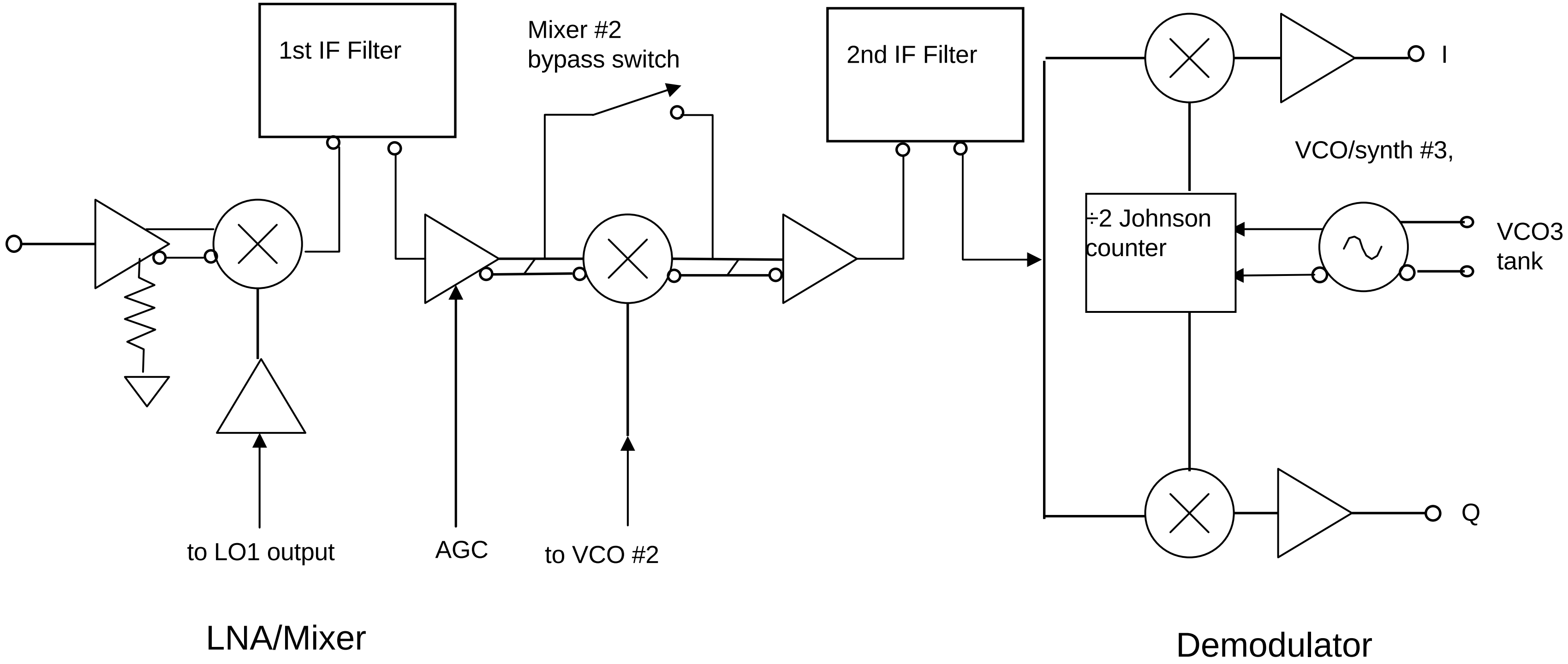

Conventional superheterodyne receiver yields best performance

Transmitter Architecture

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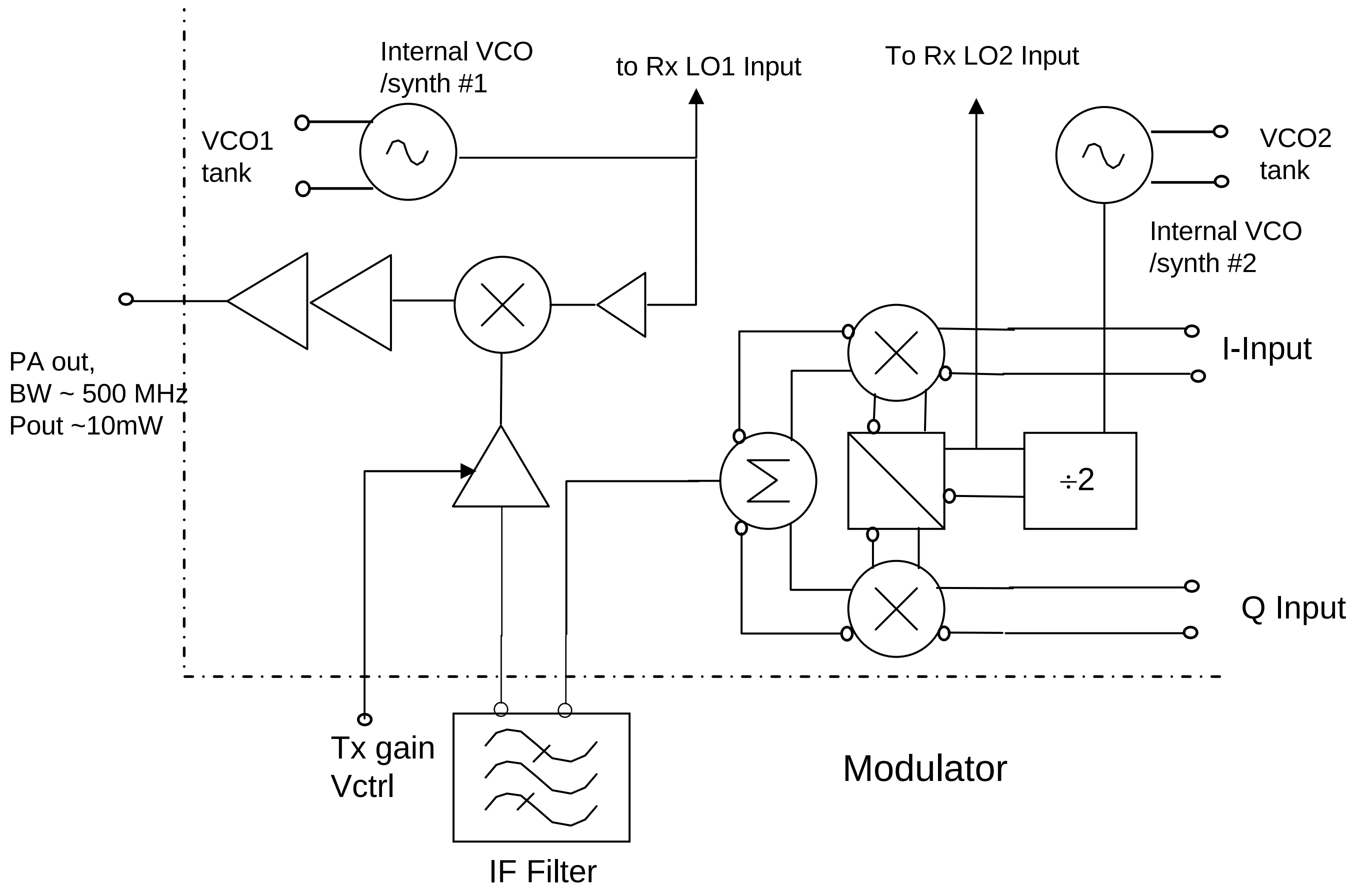

Heterodyne transmitter yields cleanest output signals

Single Chip Transceiver: Circuit Performance Design Goals

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Receiver

RF stage

- Operating frequency range — 450 MHz
- LNA-mixer noise figure — 2.8 dB
- Rx IIP3 — +9dBm @ Vdd = 5.0V

First IF stage

- 1st IF bandwidth — 1 - 45 MHz (-3dB)
- 1st IF noise figure — 15
- 1st IF input compression point — 500 mVp-p
- 1st IF gain (max) — 110 dB @ Vctrl >3.0V
- 1st IF gain (min) — -20 dB @ Vctrl < 0.8V

Second IF stage

- 2nd IF bandwidth — 20 MHz
- 2nd IF gain — 20 dB
- 2nd IF input compression point — 100 mVp-p

Single Chip Transceiver: Circuit Performance Design Goals

Honeywell

Receiver

Demodulator input P-1dB	100 mVp-p
Demodulator output bandwidth	2 MHz
Demodulator output level (max.)	1.5 Vp-p

Transmitter

PA output power (max)	12 dBm
PA compression (P-1dB)	10 dBm
PA power level control range	30 dB
PA output power (min).	-20dBm
PA bandwidth	450 MHz
Transmitter spurious signal levels (max.)	-50 dBc
Transmitter output impedance	50 ohms
Modulator leakage at PA output	< -45 dBm

Single Chip Transceiver Results

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- Chip fabricated with standard AMI 0.5um CMOS process
- All VCOs and synthesizers are fully operational
  - VCO tuning characteristics measured and used to develop PLL loop filters
- Chip is partially tested:
  - LNA/Mixer gain 13dB, P_{-1dB} measured at +5dBm
  - P_{-3dB} measured at ~+17dBm
- Gain control range closely matches simulated performance
- Demodulator gain measured at 21.7dB vs 20dB simulated performance

Initial tests show successful operation, and the chip meets design specifications

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- **The need for aeronautical datalinks**
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- ***Reconfigurable, electronically-steered antenna***

Today's Steerable Antenna Systems

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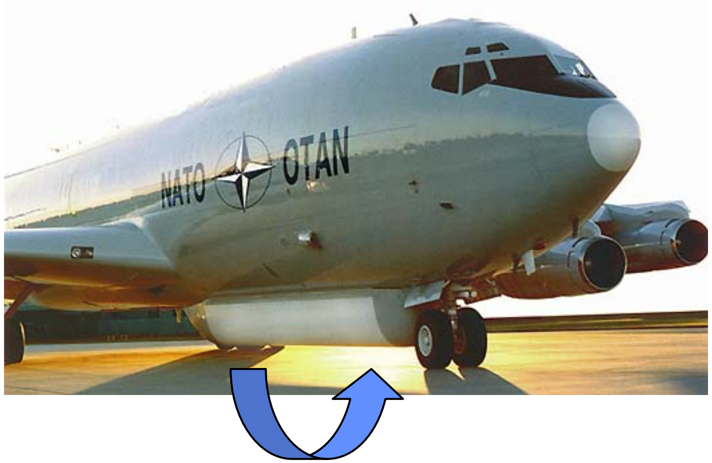
Mechanically steered antenna



Mechanically steered around longitudinal axis.
Phased array steering fore and aft.

Phased array radar allows steering of the transmit/receive beam without moving the antenna, but…

- **Requires phase shifters/time delay devices**
- **Tend to be narrow bandwidth**
- **Side lobes arise off-axis**
- **Often bulky, expensive**

Motivation for Steerable, Reconfigurable Antennas

- **Allow one aperture to perform multiple antenna functions during flight**
- **Enable steerable antennas to be used in application when phased arrays are too expensive and bulky, or insufficient space is available for mechanically steered antennas.**
- **Enable a single aperture design to operate over a broad frequency range for multiple applications**

Electronically steered, reconfigurable antennas offer benefits for commercial aviation

ESCAN: Highly Reconfigurable Antenna

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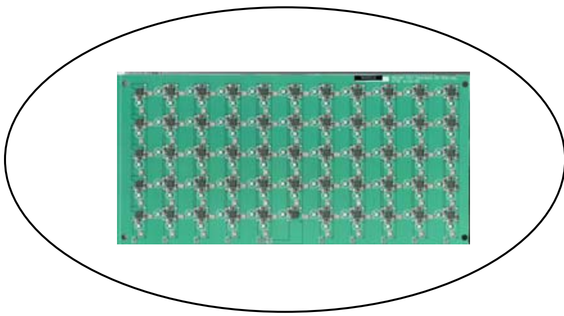
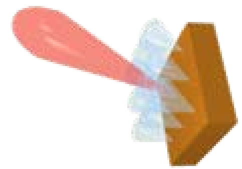
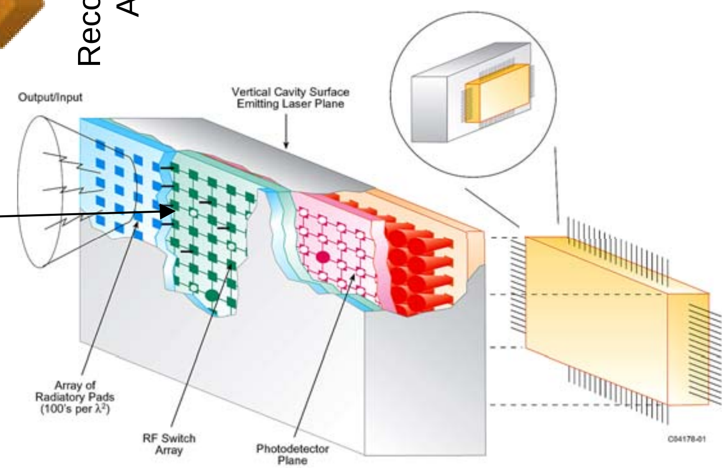
New approach:
NOT a phased array!





Reconfigurable Aperture

Multiple pads can be connected to or disconnected from a single RF feed



Georgia Tech Research Institute

- **Metal pads are connected in arbitrary configurations**
- **Reconfiguring the interconnects steers the antenna radiation**
- **A single antenna can implement a wide range of frequencies**
- **The antenna can be conformal or low profile**

Reconfigurable Aperture Overview

- **Reconfigurable apertures can alter the current distribution through their aperture.**
- **Reconfigurable arrays can change <u>element pattern</u> and vary element shape and resonant length scales beyond "smart" antennas**
- **Reconfigurable antennas contain control electronics that deliver power and reconfiguration instructions to the aperture, enabling fast reconfiguration times, and facilitating tracking (for example, of satellites)**

Reconfigurable Aperture Overview

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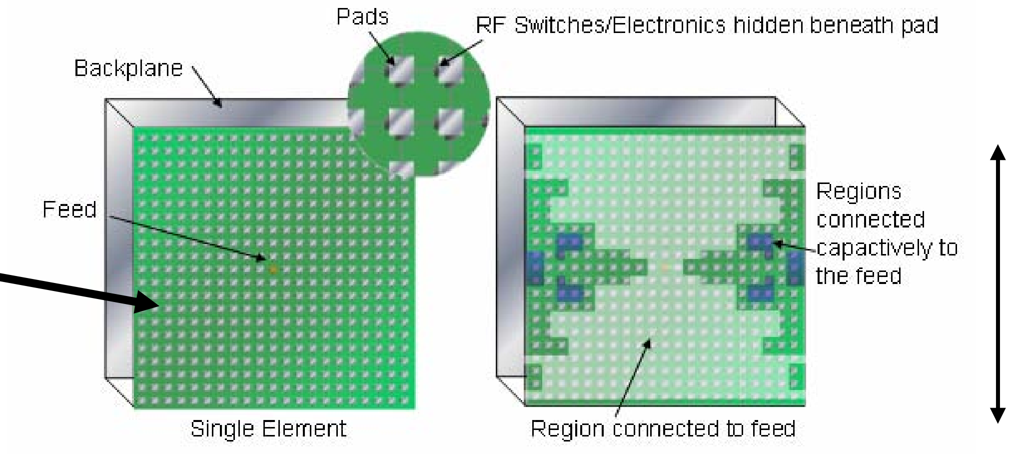
- The radiative pattern generated from a single feed element can be reconfigured with connective switches located between each pad.
  - Individual pads are much smaller than a wavelength, and are not resonant in isolation.
  - The pads connect collectively to the feed, generating radiating patterns.
  - The parasitic pads, capacitively coupled to the feed, can be configured to improve matching characteristics, enabling wider band performance.

One element (contains 400 separate pads)



25cm

Earlier Work on Reconfigurable Antennas

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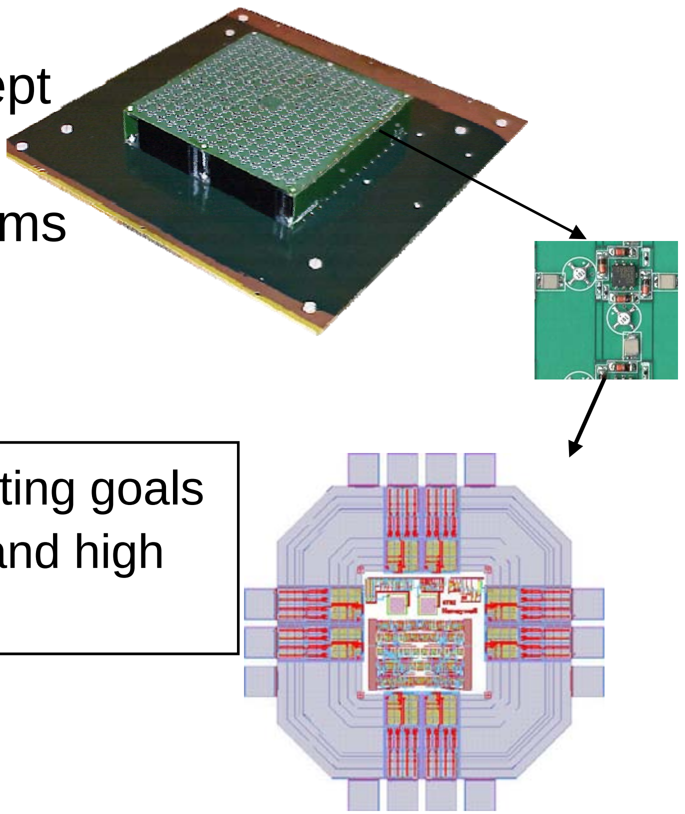
Georgia Tech Research Institute

- **ESCAN: 800MHz-2.6GHz 5x1 Reconfigurable Array**
- **Structural Form of the Element**
  - Uses proven, reconfigurable element concept developed at Georgia Tech (GTRI)[2]
  - Funded by DARPA RECAP/ FCS-C Programs

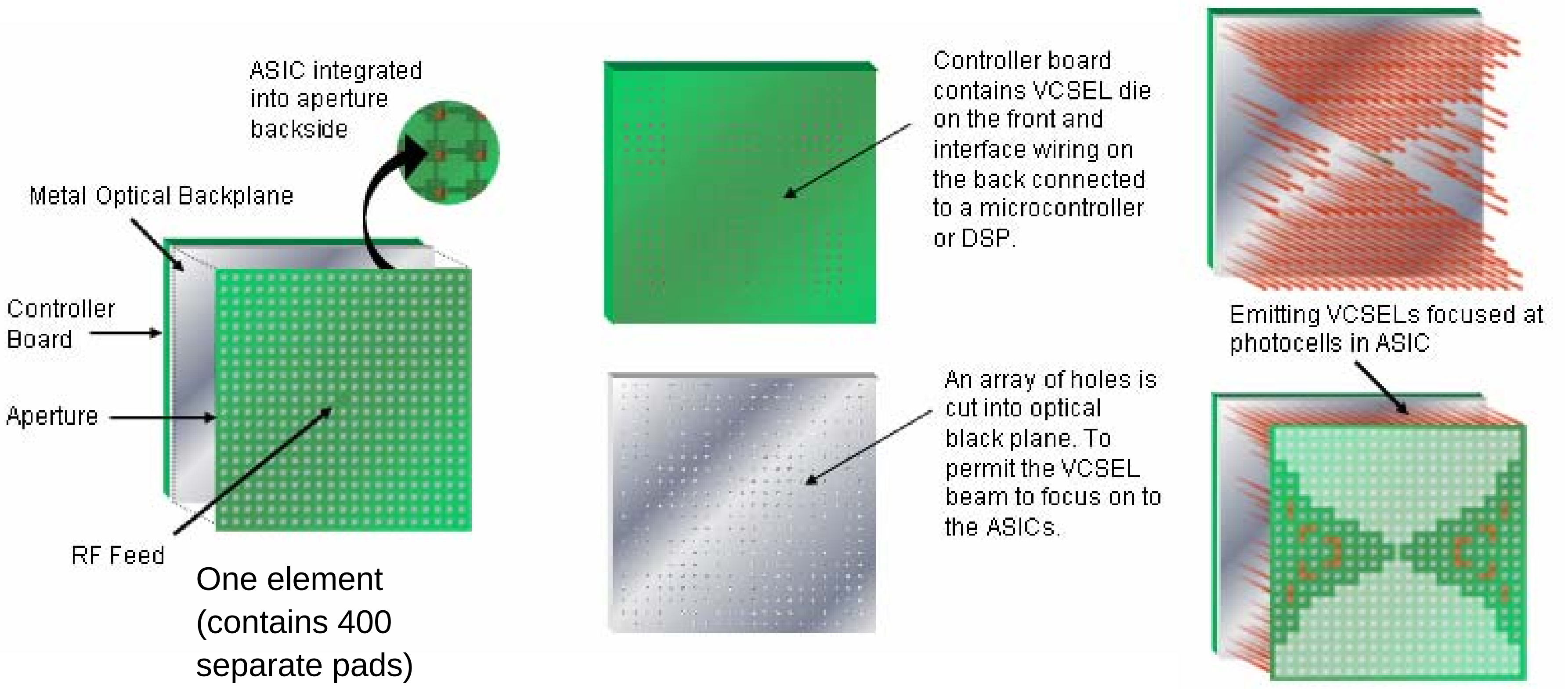


Earlier versions used electrical power feeds. Conflicting goals of low loss, minimal interference with the aperture, and high mechanical integrity made implementation difficult.

1.J. C. Maloney, M.P. Kesler, L. M. Lust, L.N. Pringle, T. L. Fountain, P. H. Harms, G.S. Smith, "Switched Fragmented Aperture Antennas," *IEEE Antennas Propagat. Soc. Int. Symposium*, Vol 1, pp. 310-313, July 2000.

ESCAN Optical Backplane

- **Power efficiency of today’s optoelectronics enables a pure optical interface and eliminates electrical problems**
  - **Electronics embedded behind each pad include a photocell and RF switch**
  - **VCSEL array is on a PCB behind the antenna ground plane**
  - **VCSEL array is controlled by 1 DSP/microcontroller per element**



File Number

ESCAN Optical Backplane

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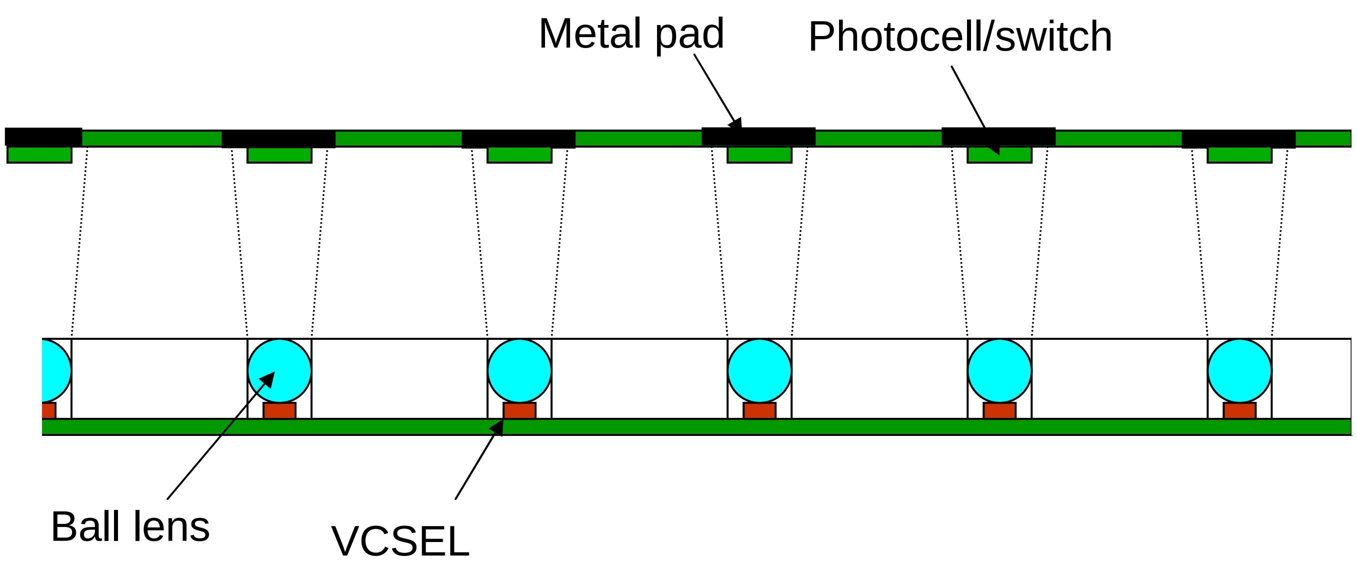
- **Each pad needs, 2 RF switches and photodetectors (PD)**
- **Switch insertion loss needs to be minimized and isolation maximized for good power handling and antenna gain**
- **VCSEL output is concentrated on photocell array to maximize photocurrent and switching speed**



(Not to scale)

ESCAN Design Goals

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- **Demonstrate operating principles compatible with:**
  - **Bandwidth: 800MHz -2.6GHz**
  - **Element broadside gain: 13dB @ 2.4GHz and 7dB @ 900Mhz**
    - Theoretical aperture gain=$4A\pi/\lambda^2$=17dB
  - **Steering: +/-70 deg**
    - Controlled by pad density and the insertion form factor of the array
  - **Power handling: 1W CW per feed at 2.4GHz**
    - Switch dependent
  - **Reconfiguration time: 20 usec**
    - Dependent on photocell
  - **Production cost: $3K-$5K/element**
  - **Simplified manufacturing**

ESCAN VCSEL & Photocell Considerations

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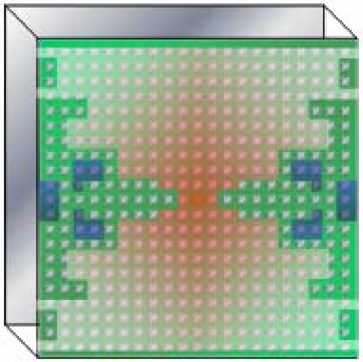
- Vertical cavity surface emitting laser
  - 850nm wavelength
  - Beam divergence ~2 degrees
  - 1.1 mm spot diameter at photovoltaic cell
  - Output power 1.5 mW
- Custom photodiode
  - 11 Cell GaAs Process
  - Photovoltaic cell area 11 x 0.25 mm2
  - Power received ~136 μW with VCSEL/optics selected
  - 1017 n-doping photovoltaic cell
  - Capacitance 92 pF, ~68 μA photocurrent@ ~0.8volts)
  - Switching time ~ 1 μs

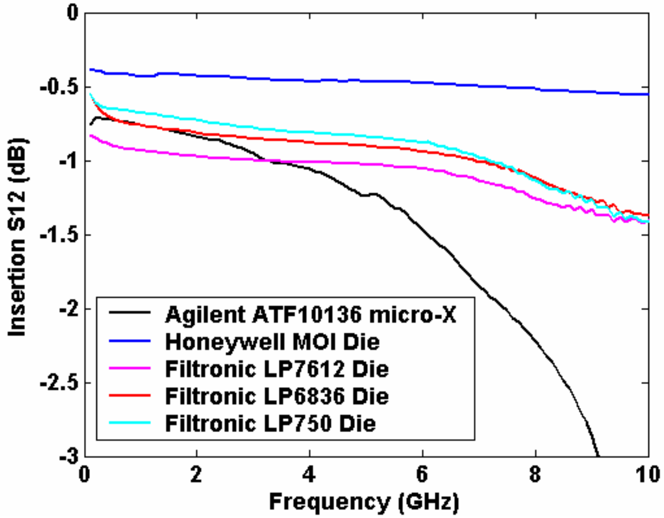
ESCAN Switch Design Considerations

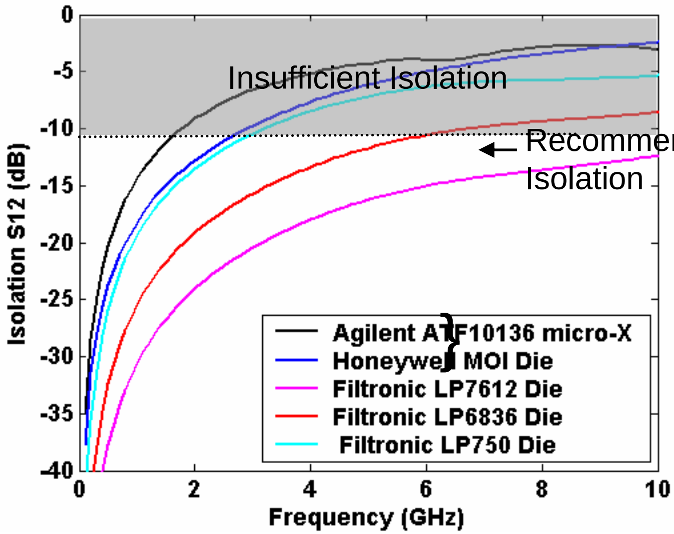
Honeywell

- **Insertion loss (IL) and Isolation**
  - **Low IL and high isolation are conflicting design goals**
  - **Insertion loss determines the physical extent of the element**
  - **Increasing insertion loss gradually degrades the realized gain continuously (target <1 dB)**
  - **Decreasing the isolation induces an abrupt change in the element performance (target <-11dB)**



High insertion loss
Currents attenuated at edges





ESCAN Switch Design Considerations

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- **Power handling and power dissipation**
  - ESCAN dissipates power even in the absence of an RF signal
  - RF power handling is limited by the RF switches in both “on” and “off”
  - 1 W per element possible with today’s switches

ESCAN Measurement

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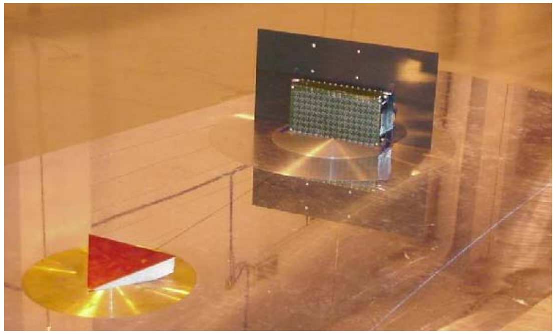
- ESCAN: thousands of reconfiguration states—a nontrivial measurement task
- Automated ground plane and range testing has been developed for specialized apertures (at GTRI for example)



Graphical User Interface for Pad Configuration

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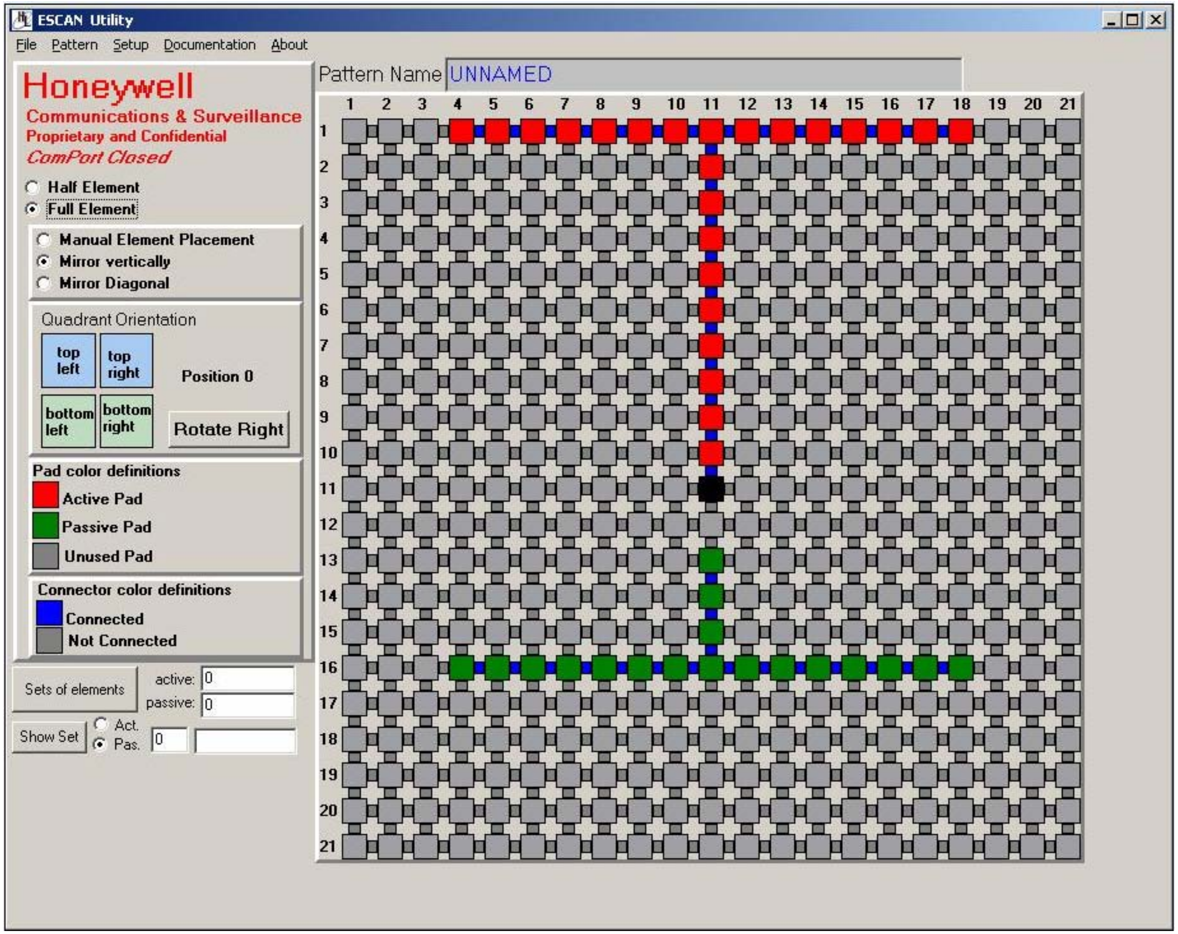
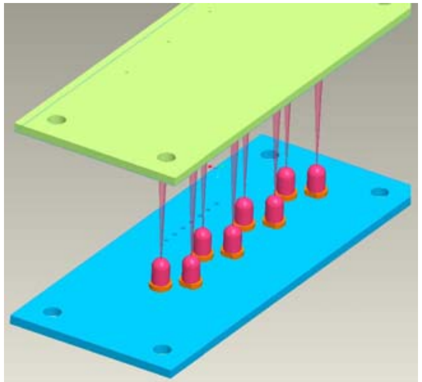


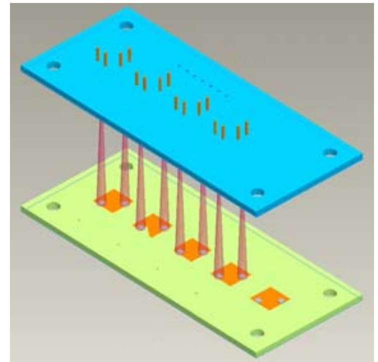
GUI dramatically simplifies pad setup for tests

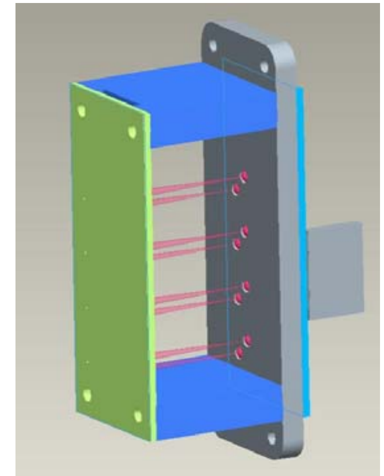
Monopole Demonstration Hardware



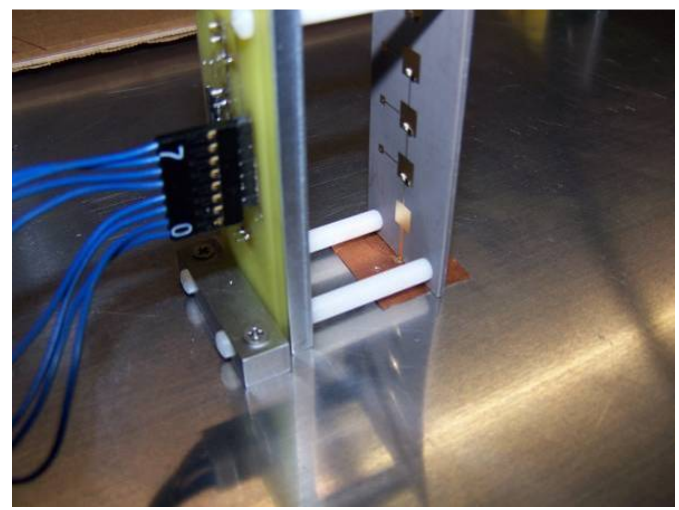
Detectors

VCSELs





5 -pad monopole used to verify optical backplane approach



Monopole Demonstration Hardware

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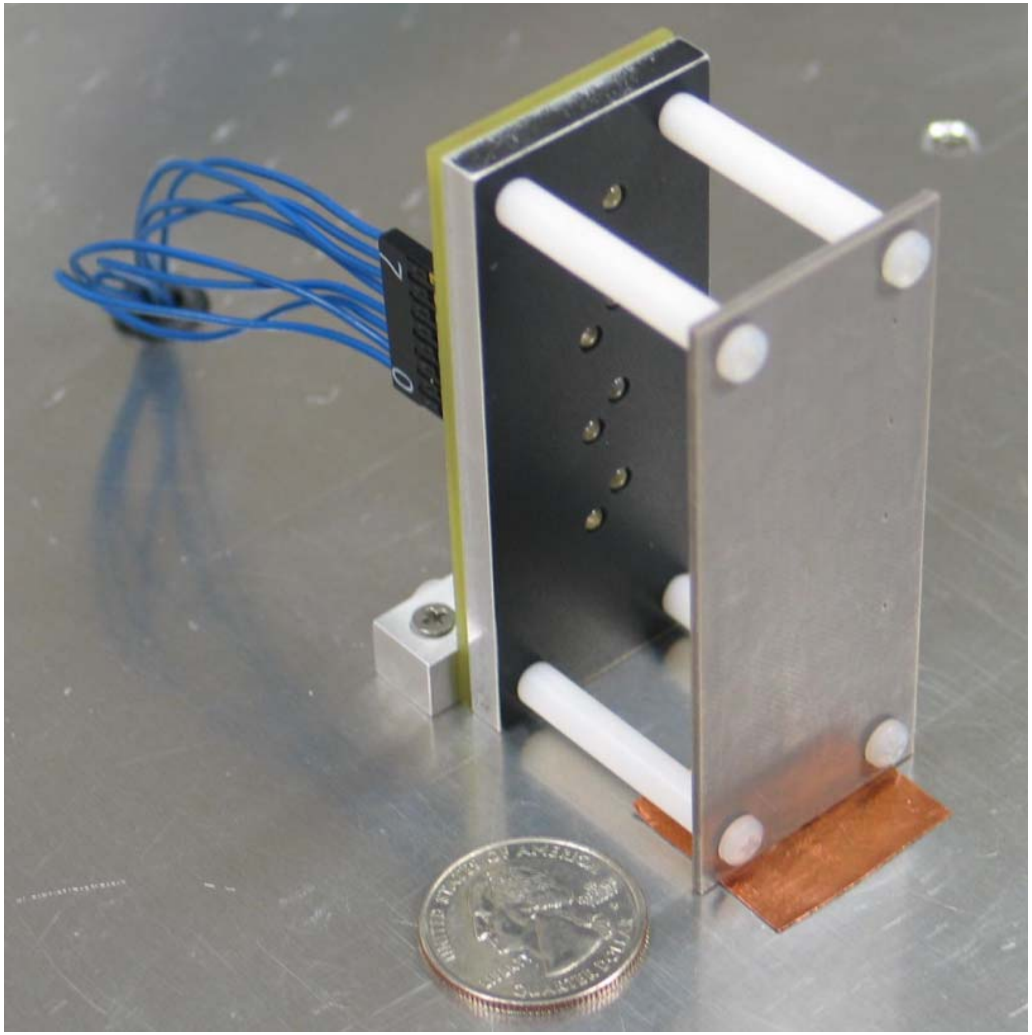

Anechoic Chamber Test